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**INFLUENCE OF OPERATIONAL FACTORS ON IMPORTANCE OF
SCENE PROPERTIES FOR VISUAL LOW-ALTITUDE FLIGHT**

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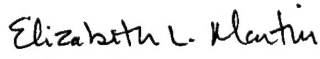
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PREFACE

This effort was conducted at the Armstrong Laboratory, Aircrew Training Research Division (AL/HRA) at Williams Air Force Base, AZ, in support of training research and development to maintain air combat readiness and visual scene and display requirements.

This work was performed by the University of Dayton Research Institute (UDRI) in support of Work Unit No. 1123-32-03, Tactical Scene Content Requirements, Principal Investigator, Dr. Elizabeth L. Martin, and 1123-03-85, Flying Training Research Support, Contract No. F33615-90-C-0005. Contract Monitor was Ms. Patricia A. Spears. One of the objectives of this work unit is to identify flight simulator visual scene content factors that contribute to training effectiveness for low-altitude flight.

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INFLUENCE OF OPERATIONAL FACTORS ON IMPORTANCE OF SCENE PROPERTIES FOR VISUAL LOW-ALTITUDE FLIGHT

INTRODUCTION

Limitations in computer image generation (CIG) and display technology preclude flight simulator visual scenes that contain all of the variety and complexity found in real-world scenes. A fundamental question facing designers of flight simulator visual scenes concerns which specific scene properties are most important to pilots. Previous research has revealed two dimensions of real-world scenes that are important to pilots in the context of visual low-altitude flight: (a) variation in terrain contour mediated by presence/absence of hills and ridges, and (b) variation in the conspicuity of objects in scenes mediated by size, spacing, contrast and familiar appearance (Kleiss, 1990, 1992). Importance of scene properties may reflect basic visual abilities that underlie normal environmental interaction or learning associated with this activity. If so, the same simulator scenes would be likely to be effective across a range of training situations. However, low-altitude flight may impose unique demands on pilots such that they become attuned to different scene properties with experience. In this event, effective training would require consideration of these differences in the design of simulator visual scenes.

Results reported by Kleiss (1990) tend to support this latter possibility. Two A-10 pilots weighted Dimension 2, object size and spacing, disproportionately more heavily than Dimension 1, variation in terrain contour, in contrast to 13 pilots of A-7 and F-5 aircraft in a sample. Subsequent replications of this experiment with two samples totaling 33 F-4 and F-16 pilots revealed only one additional pilot who showed a similar disproportionate weighting of the objects dimension compared to terrain contour dimension (Kleiss, 1992). The implication is that some factor unique to the two A-10 pilots produced a shift in the relative importance of scene properties.

The two A-10 pilots in the Kleiss (1990) investigation were stationed in the eastern United States where terrain is rich in vegetation. Other pilots were stationed in the southwest United States where vegetation is relatively sparse. A reasonable hypothesis is that experience flying in a different geographic region affected the relative importance of scene properties. Although no A-10 pilots were included in the Kleiss (1992) investigation, one sample was drawn from a population of pilots stationed in Germany whereas the other was drawn from a population stationed in the southwest United States. Although the terrain in Germany is similar to that in the eastern United States, no differences were evident in the results for these two samples suggesting that geographic region familiar to pilots is not an important factor.

Operational factors for the A-10 differ in potentially important ways from other aircraft investigated thus far. It is relatively slower (250-300 knots) and its missions frequently entail multiple attacks on ground targets in a limited geographic region. In contrast, missions for the A-7, F-4, F-5 and F-16 aircraft frequently involve a fast (400-500 knots) ingress to a predetermined target area followed by a single pass on a target and then a fast egress from the target area. These differences could conceivably motivate different visual strategies that emphasize different properties of scenes.

The possibility that operational factors affect the relative importance of scene properties implies that simulator visual scenes should be tailored to specific applications for maximum training effectiveness. Before accepting this possibility, it was deemed prudent to replicate the apparent difference for A-10 pilots using an entire group of A-10 pilots. For comparison, a group of F-16 pilots was included who have previously provided evidence of an emphasis on terrain contour (Kleiss, 1992). To extend results to a broader cross section of the Air Force fighter

community, a group of F-111 pilots was also included. Speed and mission characteristics for the F-111 are similar to the F-16. However, the F-111 has a large nose section and a side-by-side crew seating arrangement which limits out-of-the-cockpit visibility for the pilot and could force attention to different scene properties.

Two additional groups served as controls. The first group consisted of nonpilots who had no previous piloting experience. This group provided a baseline for comparing the influence of general piloting experience and ability. The second group consisted of Air Force pilots with little or no operational low-altitude experience. This group provided a baseline for comparing the influence of formal low-altitude training on subjects with demonstrated piloting abilities.

METHOD

Subjects

F-16. This group consisted of 17 mission-qualified F-16 pilots from the 10th, 313th and 496th Tactical Fighter Squadrons (TFS), Hahn and Ramstein Air Bases, Germany. Pilots averaged 1,323 hours total flying time ($SD = 735$, $R = 2,600$) and 276 hours in the F-16 ($SD = 161$, $R = 600$). Typical missions for all pilots included flying at altitudes between 100 and 500 feet above ground level (AGL).

A-10. This group consisted of 19 mission-qualified A-10 instructor pilots (IPs) from the 333rd, 357th and 358th Tactical Fighter Training Squadrons (TFTS), Davis-Monthan Air Force Base, Tucson, AZ. Pilots averaged 1,680 hours total flying time ($SD = 659$, $R = 2,250$) and 1,178 hours in the A-10 ($SD = 325$, $R = 1,200$). Typical missions for all pilots included flying at altitudes between 100 and 500 feet AGL.

F-111. This group consisted of 18 mission-qualified pilots and IPs from the 522nd and 523rd TFSS, and the 358th TFTS, Cannon AFB, NM. Pilots averaged 1,397 hours total flying time ($SD = 1,083$, $R = 4,175$) and 772 hours in the F-111 ($SD = 578$, $R = 1,910$). Hours in the F-111 are based on data from only 17 pilots as one pilot had previous experience in a variant of the F-111, the FB-111, but did not report the number of hours. Typical missions for all pilots included flying at altitudes between 100 and 500 feet AGL.

A one-way analysis of variance (ANOVA) on total hours flying time revealed no differences among the three groups of expert pilots [$F(2,51) < 1$]. A one-way ANOVA on hours in each aircraft type was significant [$F(2,50) = 23.83$, $p < .001$]. Pairwise comparisons using Scheffe's method revealed that all three means differed significantly from one another beyond the $p = .05$ level of confidence.

Inexperienced. This group consisted of 12 U. S. Air Force pilots who had little or no operational low-altitude flight training. Eight were IPs in the T-37 or T-38 aircraft from the 96th, 97th, 98th and 99th Flying Training Squadrons, Williams AFB, AZ. Four were recent graduates of undergraduate pilot training (UPT). IPs averaged 1,151 hours total flying time ($SD = 407$, $R = 1250$) and recent UPT graduates averaged 280 hours total flying time ($SD = 54$, $R = 120$). IPs had no previous operational experience at altitudes below 500 feet AGL. Three of four recent UPT graduates were students in the A-10 and F-111 aircraft with fewer than 80 hours in the aircraft and minimal low-altitude experience.

Nonpilot. This group consisted of 24 undergraduate students enrolled in a psychology course at Arizona State University. None had previous piloting experience.

Stimuli, Design and Materials

Stimuli were the same used by Kleiss (1992, Experiment 2) and consisted of 17, 5-second videotape segments depicting low-altitude, high-speed flight over a variety of terrain types. A frame from each videotape segment is shown in Appendix A. All segments except the forested mountain were shot at an altitude of approximately 125 feet AGL and a speed of 350 knots using a 16 mm motion picture camera equipped with a 12.5 mm wide angle lens. Film was subsequently transferred to videotape and the video speed was increased to produce the appearance of approximately 420 knots. This speed is within the range typically flown by F-16 and F-111 aircraft but is somewhat faster than the 250 to 300 knots typically flown by the A-10. The forested mountain scene was obtained from Air Force files. Speed and altitude are unknown, but appear to be close to those depicted in other segments.

Seventeen stimuli yielded a total of 136 unique pairwise combinations. The length of time required to present all stimulus pairs was judged to be prohibitively long, so an incomplete data design was used in which each subject viewed only half (68) of the pairs (Schiffman, Reynolds & Young, 1981). Stimulus pairs were arranged in random order on two videotapes with the constraints that each segment appeared approximately equally often on each tape, and that no segment appeared in consecutive pairs. Segments within a pair were presented sequentially. Two additional videotapes were similarly constructed by reversing the order of presentation of segments in each pair and then randomizing the sequence of pairs. A number preceded each stimulus pair indicating the position of that pair in the sequence (1 through 68). A one-second blank separated each segment within a pair and a three-second blank followed each pair providing time to enter responses. A cathode ray tube (CRT) projector was used to display stimulus segments and provided a 44.6° horizontal by 32° vertical image viewed from a distance of approximately 12 feet. No problems were reported due to the rapid pace of the videotape presentation.

Following Schiffman, Reynolds and Young (1981), similarity judgments were recorded on 120 mm lines anchored at the left with "exact same" and at the right with "completely different." Rating scales were arranged in a booklet, four scales per page, each numbered in sequence. An instruction page appeared at the front of the booklet and described the purpose of the experiment and the rating procedure. A copy of this page is shown in Appendix B.

To aid dimensional interpretation, subjects rated each scene on eight bipolar scales, each 120 mm in length, which reflected a variety of scene attributes thought to be of possible relevance to pilots. Each of the eight scales for a given scene appeared on a single page with the following dichotomous anchor labels:

1. "Prefer" versus "Do not prefer"
2. "Hilly/mountainous" versus "Flat"
3. "Objects" versus "No objects"
4. "Known size references" versus "No known size references"
5. "Texture/detail" versus "No texture/detail"
6. "Complex" versus "Simple"
7. "Regular" versus "Random"
8. "High contrast" versus "Low contrast"

These terms will be explained in greater detail later. Bipolar scales appeared at the end of the booklet after the similarity scales.

Procedure

Data were collected in small groups of one to four subjects. Subjects began by reading the instruction sheet at the front of the response booklet. Subjects were encouraged to restrict their similarity judgments to scene properties useful for controlling altitude during low-altitude flight. If questions arose regarding the rating task, it was simply noted that dissimilarity between scenes could result from absence of relevant properties in one of the two scenes comprising a pair or presence of a fundamentally different property. Subjects were encouraged to use the entire range available on the rating scales. To familiarize subjects with the range of stimuli used in the investigation, scenes were shown individually prior to presentation of stimulus pairs. Approximately equal numbers of subjects viewed each of the four stimulus tapes.

After completing similarity ratings, subjects rated individual scenes on the eight bipolar attribute scales. Subjects reviewed the anchor labels prior to beginning so that ambiguities regarding the specific attributes being rated could be clarified. The following definitions were provided in the event of questions:

1. "Prefer" versus "Not prefer" - extent to which the pilot preferred the cues depicted in a given scene.
2. "Hilly/mountainous" versus "Flat" - presence/absence of hills and/or mountains.
3. "Objects" versus "No objects" - presence/absence of discernible objects.
4. "Known size references" versus "No known size references" - extent to which the apparent size of familiar features is a cue for distance.
5. "Texture/detail" versus "No texture detail" - visibility of detail in scenes (emergence of detail can be a cue for approach to an object or surface).
6. "Complex" versus "Simple" - cluttered or noisy appearance of scene.
7. "Regular" versus "Random" - extent to which spacing or positioning of scene features is orderly and predictable.
8. "High contrast" versus "Low contrast" - extent to which features stand out against the background, either light on dark or dark on light.

Subjects viewed scenes one at a time completing all eight bipolar scales before progressing to the next scene. The entire session took approximately one hour.

RESULTS

Three analyses were performed. The first was multidimensional scaling (MDS) of similarity ratings using ALSCAL (Young, Takane & Lewycky, 1978). Ratings were distances in millimeters measured from the left end of each scale to the point at which the subject marked the scale. Values ranged from 0 to 120 with larger values denoting greater dissimilarity. An individual differences option was used which provides as output subject weights that reflect the relative importance (in the sense of variance explained) of each dimension to each individual subject. Data were treated as ordinal. Missing stimulus pairs were treated as missing values.

The second analysis was a multiple regression of MDS dimensional coordinates on attribute ratings for bipolar scales (Kruskal & Wish, 1986). Attribute ratings were also distances in millimeters measured from the left end of each scale to the point at which the subject marked the scale. Values ranged from zero to 120. Presence of attributes was generally associated with the left end of each scale and, therefore, denoted by smaller numeric values.

The third analysis was a hierarchical cluster analysis using Ward's method (SAS Institute Inc., 1990). Data were MDS dimensional coordinates and the number of clusters was simply that for which no cluster contained fewer than three stimuli.

Figure 1 shows stress and squared correlations (RSQ) derived from MDS analyses plus stress for purely random data (stimulus set size equal to 17 stimuli, Spence & Ogilvie, 1973) as a function of increasing dimensionality. Also shown is RSQ between interpoint Euclidian distances and disparities derived from similarity ratings. One-dimensional solutions are not computed by ALSCAL with the individual differences approach.

Isaac and Poor (1974) argued that correct dimensionality (i.e., dimensionality with maximum structure) is that at which stress for experimental data and stress for purely random data are most different. Stress values for experimental data are comparable in magnitude across groups and differ most from random stress at dimensionality equal to two. Squared correlations for two-dimensional solutions range from approximately .75 to .80.

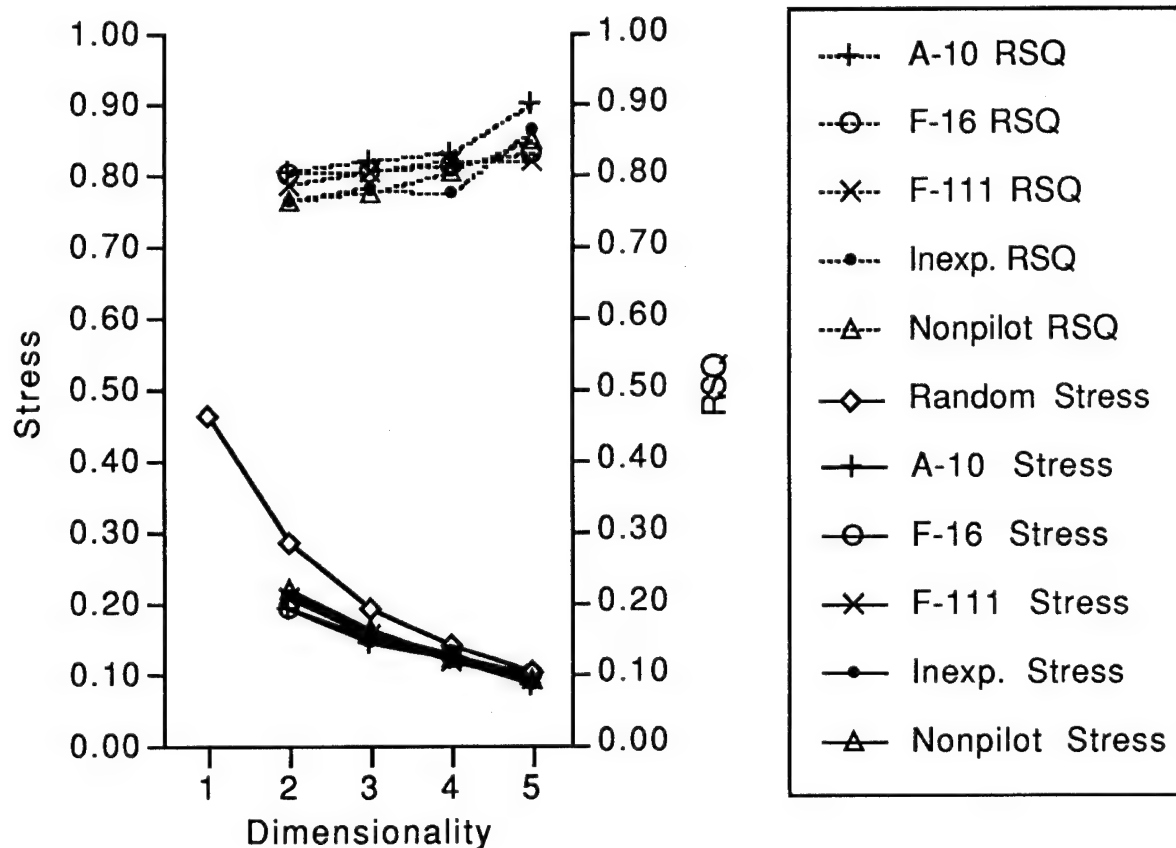


Figure 1
Stress and RSQ for Experimental Data and Stress for Random Data
as a Function of Dimensionality

Bipolar attribute ratings were regressed on two-dimensional stimulus coordinates for each group. For each group, the largest regression weight for one of the two dimensions was for ratings of the hilly/mountainous nature of scenes. Scaling of axes is arbitrary, so this dimension was taken to be Dimension 1 for each group. Coordinates were scaled so that the presence of properties, which was generally indicated by small numeric values, was associated with positive dimensional coordinates. Regression weights in this case were negative. Kruskal and Wish (1986) suggest an attribute may provide a reasonable interpretation of a dimension if (a) the regression weight for that dimension is large and (b) the multiple R is large (.90s are good, but .80s and .70s may suffice) and statistically reliable beyond $p = .01$. In the present case, bipolar scales were accepted for consideration if they had the largest regression weight on a given dimension. If more than one scale had a regression weight exceeding .90 on a given dimension, then the three largest were accepted.

Tables 1 through 5 show regression weights and multiple Rs for bipolar scales within each group. Anchor labels reflecting the left (i.e., numerically smallest) end of each attribute scale are shown for identification. Regression weights have been converted to direction cosines by normalizing so that they sum to one when squared. This allows a property vector to be drawn through the origin of MDS spatial configurations indicating the direction through multidimensional space that corresponds to rated increases in the amount of a given attribute.

Table 1. Results of Multiple Regression Analyses for F-16 Pilots

Scale	Regression Weights		Multiple R
	Dimension 1	Dimension 2	
1. Prefer	-0.065	-0.998	0.917*
2. Hilly/mountainous	-0.992	0.124	0.965*
3. Objects	-0.175	-0.985	0.914*
4. Known size references	-0.114	-0.994	0.910*
5. Texture/detail	-0.230	-0.973	0.921*
6. Complex	-0.770	-0.637	0.888*
7. Regular	0.999	0.052	0.821*
8. High contrast	-0.074	-0.994	0.868*

* $p < .001$

Table 2. Results of Multiple Regression Analyses for A-10 Pilots

Scale	Regression Weights		Multiple R
	Dimension 1	Dimension 2	
1. Prefer	0.145	-0.989	0.942*
2. Hilly/mountainous	-0.964	-0.265	0.956*
3. Objects	0.297	-0.955	0.947*
4. Known size references	0.265	-0.964	0.956*
5. Texture/detail	0.179	-0.984	0.920*
6. Complex	-0.149	-0.989	0.899*
7. Regular	0.453	0.892	0.506 n.s.
8. High contrast	0.418	-0.908	0.926*

* $p < .001$

Table 3. Results of Multiple Regression Analyses for F-111 Pilots

Scale	Regression Weights		Multiple R
	Dimension 1	Dimension 2	
1. Prefer	0.647	-0.763	0.909**
2. Hilly/mountainous	-0.822	-0.569	0.951**
3. Objects	0.604	-0.797	0.892**
4. Known size references	0.613	-0.790	0.886**
5. Texture/detail	0.524	-0.852	0.854**
6. Complex	0.183	-0.983	0.861**
7. Regular	0.657	0.754	0.644*
8. High contrast	0.766	-0.643	0.847**

* $p < .05$

** $p < .001$

Table 4. Results of Multiple Regression Analyses for Inexperienced Pilots

Scale	Regression Weights		Multiple R
	Dimension 1	Dimension 2	
1. Prefer	0.318	-0.948	0.885**
2. Hilly/mountainous	-0.873	-0.488	0.901**
3. Objects	0.397	-0.918	0.917**
4. Known size references	0.365	-0.931	0.913**
5. Texture/detail	0.352	-0.934	0.903**
6. Complex	0.116	-0.993	0.879**
7. Regular	-0.116	0.993	0.647*
8. High contrast	0.598	-0.802	0.882**

* $p < .05$

** $p < .001$

Table 5. Results of Multiple Regression Analyses for Nonpilots

Scale	Regression Weights		Multiple R
	Dimension 1	Dimension 2	
1. Prefer	0.844	-0.535	0.750*
2. Hilly/mountainous	-1.000	0.000	0.982**
3. Objects	-0.461	-0.898	0.829**
4. Known size references	-0.286	-0.957	0.877**
5. Texture/detail	-0.264	-0.966	0.803**
6. Complex	-0.850	-0.524	0.876**
7. Regular	0.968	0.246	0.762*
8. High contrast	-0.075	-0.994	0.723*

* $p < .01$

** $p < .001$

With the individual differences option, ALSCAL provides as output subject weights which reflect the relative importance of each dimension to each individual subject. The extent to which a subject's weights are proportional to the group is indexed by weirdness. A subject with one large weight and one (or more) small weights has a weirdness near one whereas a subject with weights proportional to the group has a weirdness near zero, the minimum value. Squared subject weights sum to RSQ for individual subjects. When averaged across subjects for each dimension, squared subject weights also provide an estimate of variance explained by each dimension for the group. However, because data are ordinal in nature and do not satisfy the metric properties that underlie usual interpretations of variance, these values must be taken as estimates.

Tables 6 through 10 show subject weights and weirdness values for subjects within each group plus means for squared subject weights averaged across dimensions. Dimension 1 accounted for most variance in similarity ratings (and is, therefore, the most important dimension in this sense) for F-16 pilots and nonpilots, whereas Dimension 2 accounted for most variance for F-111, A-10 and inexperienced pilots. Weirdness values are generally small indicating that subjects were consistent with regard to the relative importance of dimensions. Not more than one subject within each group had a weirdness value exceeding 0.500 and a pattern of weights opposite that of the group average.

Table 6. Subject Weights and Weirdness for F-16 Pilots

Subject	Subject Weights		Weirdness
	Dimension 1	Dimension 2	
1	0.832	0.420	0.107
2	0.874	0.287	0.360
3	0.436	0.700	0.546
4	0.670	0.631	0.281
5	0.794	0.392	0.121
6	0.857	0.269	0.384
7	0.655	0.532	0.193
8	0.719	0.530	0.133
9	0.870	0.289	0.353
10	0.762	0.447	0.011
11	0.865	0.261	0.405
12	0.808	0.434	0.067
13	0.680	0.538	0.177
14	0.667	0.569	0.222
15	0.789	0.500	0.038
16	0.788	0.457	0.019
17	0.762	0.406	0.073
Average Squared Subject Weights (RSQ)	0.581	0.218	

Table 7. Subject Weights and Weirdness for A-10 Pilots

Subject	Subject Weights		Weirdness
	Dimension 1	Dimension 2	
1	0.538	0.727	0.080
2	0.292	0.830	0.494
3	0.637	0.618	0.129
4	0.691	0.547	0.254
5	0.481	0.703	0.128
6	0.298	0.844	0.492
7	0.901	0.290	0.665
8	0.477	0.756	0.179
9	0.619	0.699	0.035
10	0.612	0.695	0.031
11	0.668	0.608	0.169
12	0.693	0.590	0.210
13	0.574	0.595	0.089
14	0.740	0.568	0.272
15	0.427	0.816	0.290
16	0.186	0.893	0.690
17	0.708	0.478	0.344
18	0.362	0.785	0.360
19	0.685	0.584	0.209
Average Squared Subject Weights (RSQ)	0.342	0.462	

Table 8. Subject Weights and Weirdness for F-111 Pilots

Subject	Subject Weights		Weirdness
	Dimension 1	Dimension 2	
1	0.620	0.589	0.100
2	0.456	0.736	0.232
3	0.653	0.636	0.086
4	0.598	0.532	0.142
5	0.538	0.523	0.087
6	0.842	0.413	0.472
7	0.583	0.665	0.015
8	0.292	0.869	0.543
9	0.401	0.827	0.369
10	0.851	0.380	0.514
11	0.641	0.648	0.062
12	0.608	0.675	0.003
13	0.780	0.415	0.433
14	0.468	0.794	0.260
15	0.745	0.521	0.286
16	0.521	0.549	0.036
17	0.332	0.866	0.486
18	0.362	0.832	0.419
19	0.367	0.584	0.209
Average Squared Subject Weights (RSQ)	0.354	0.430	

Table 9. Subject Weights and Weirdness for Inexperienced Pilots

Subject	Subject Weights		Weirdness
	Dimension 1	Dimension 2	
1	0.713	0.511	0.255
2	0.471	0.749	0.241
3	0.634	0.612	0.072
4	0.601	0.643	0.007
5	0.651	0.476	0.242
6	0.677	0.501	0.236
7	0.788	0.483	0.343
8	0.415	0.763	0.324
9	0.572	0.672	0.053
10	0.470	0.710	0.210
11	0.424	0.770	0.317
12	0.578	0.668	0.043
Average Squared Subject Weights (RSQ)	0.353	0.408	

Table 10. Subject Weights and Weirdness for Nonpilots

Subject	Subject Weights		Weirdness
	Dimension 1	Dimension 2	
1	0.921	0.223	0.422
2	0.876	0.241	0.355
3	0.593	0.520	0.345
4	0.844	0.301	0.205
5	0.773	0.339	0.078
6	0.762	0.515	0.195
7	0.737	0.338	0.048
8	0.837	0.440	0.038
9	0.883	0.252	0.335
10	0.564	0.426	0.262
11	0.934	0.106	0.712
12	0.770	0.417	0.057
13	0.574	0.524	0.368
14	0.836	0.334	0.136
15	0.811	0.396	0.010
16	0.540	0.638	0.495
17	0.705	0.529	0.257
18	0.833	0.379	0.054
19	0.809	0.367	0.055
20	0.775	0.470	0.129
21	0.748	0.443	0.114
22	0.766	0.339	0.072
23	0.852	0.256	0.306
24	0.704	0.342	0.013
Average Squared Subject Weights (RSQ)	0.602	0.159	

Figures 2 through 6 show two-dimensional spatial configurations derived from MDS analyses for each group. Axes reflect the range of stimuli along each dimension. Dotted lines are property vectors drawn through the origins of spatial configurations corresponding to attributes with largest regression weights in Tables 1 through 5. Concentric contours reflect growth of clusters as stimuli met the criterion for inclusion in the cluster.

Results for F-16 pilots (Fig. 2) replicate in detail those obtained previously by Kleiss (1992) using pilots of fast, single-seat, fighter-type aircraft. Five scenes rich in hills and ridges are clustered at the extreme positive end of Dimension 1 whereas flat scenes are positioned at the extreme negative end of the dimension. Alignment of the hilly/mountainous property vector with this dimension suggests that the property captured by this dimension pertains to presence or absence of hills and ridges. Positioning of scenes with large buildings and groups of large trees midway along Dimension 1 suggests that vertical development of these objects is to some extent important. As in previous experiments, scenes with large mountains obstructing the horizon are not systematically represented along the Dimension 1 axis indicating that the important property captured by this dimension is presence or absence of undulations in the terrain surface rather than large vertical obstructions. Also consistent with Kleiss' (1992, Experiment 2) results is alignment of the regular/predictable property vector with this dimension pointing toward flat scenes. Undulations in the terrain surface, therefore, add an element of randomness and unpredictability to scenes.

Scenes with large buildings and groups of large trees form a single cluster positioned at the positive end of Dimension 2. Property vectors aligned with Dimension 2 suggest that the important properties exhibited by these scenes are large, high-contrast boundaries and identifiable size. Scenes with small, evenly spaced vegetation are positioned near the middle of the dimension and scenes that lack distinct objects and vegetation are positioned at the extreme negative end of the dimension. Flat scenes with small, dense vegetation cluster separately near the middle of the dimensional axis. The ordering of scenes along the Dimension 2 axis is consistent with an interpretation along the lines of object size and spacing. The prototypical exemplars of this property are large, spatially distinct objects. Alignment of the known size property vector with this dimension suggests that pilots can more easily judge the size of large, spatially distinct objects. This property is preferred by pilots compared to hills and ridges captured by Dimension 1.

The spatial configuration for nonpilots (Fig. 6) appears most similar to that for F-16 pilots. The composition of clusters is somewhat different due to positioning of the desert, grassland, agricultural and forested mountain scenes nearer the negative end of the Dimension 2 axis. This suggests reduced importance of an undifferentiated distribution of vegetation in scenes. Further evidence for this is provided in Table 10 where it can be seen that the average squared subject weight for Dimension 2, the dimension along which differences in objects and vegetation are captured, is proportionately smaller than Dimension 1 compared to F-16 pilots (Table 6). Similar global structure, however, argues for dimensional interpretations similar to those for F-16 pilots.

Spatial configurations for A-10, F-111, and inexperienced pilots (Figs. 3, 4, & 5) bear certain similarities to that for F-16 pilots. Five scenes containing hills and ridges are consistently clustered at the extreme positive end of Dimension 1 whereas the airport scene is consistently positioned at the extreme positive end of Dimension 2. However, differences are evident in spatial configurations that argue for slightly different dimensional interpretations.

For A-10 pilots (Fig. 3), the ordering of scenes along the Dimension 1 axis is consistent with an interpretation of this dimension along the lines of presence or absence of undulations in the terrain surface. Scenes containing an undifferentiated distribution of vegetation are positioned nearer the negative end of Dimension 2 forming a single large cluster with scenes that contain little

or no vegetation. The valley, hills w/trees and desert w/trees scenes which contain larger and more distinct vegetation are also positioned nearer the positive end of Dimension 2. This suggests an interpretation of Dimension 2 along the lines of presence or absence of discrete objects in scenes. Large objects remain the prototypical exemplars of this property. Alignment of the complexity property vector with Dimension 2 suggests that discrete objects add to the perceived complexity of scenes. Alignment of the texture/detail property vector with Dimension 2 suggests that small-scale properties such as branches and leaves on trees or details on buildings are also important. Consistent with results of Kleiss (1990), data in Table 7 show that Dimension 2 is more important than Dimension 1.

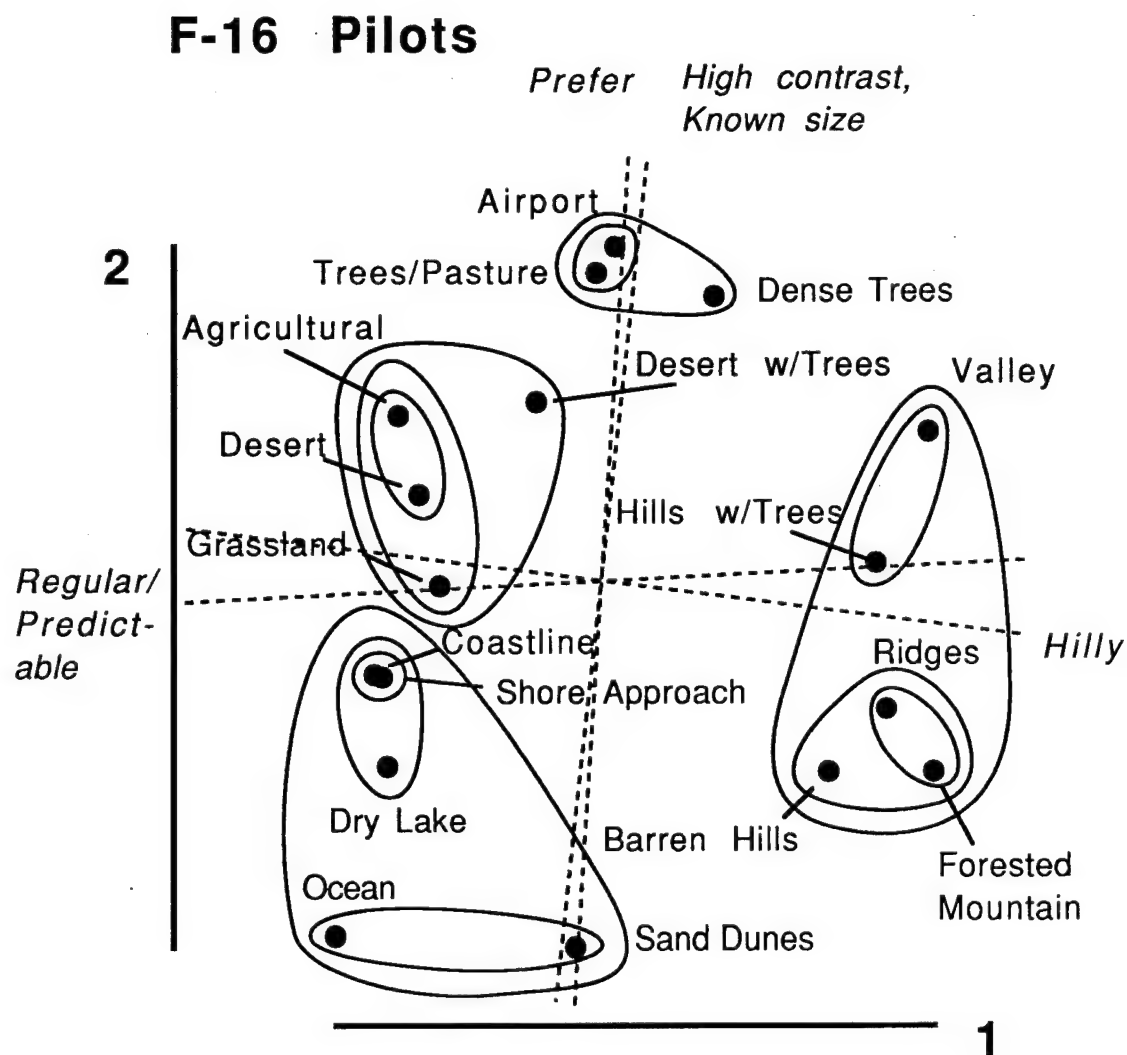


Figure 2
Two-Dimensional Spatial Configuration for F-16 Pilots

A-10 Pilots

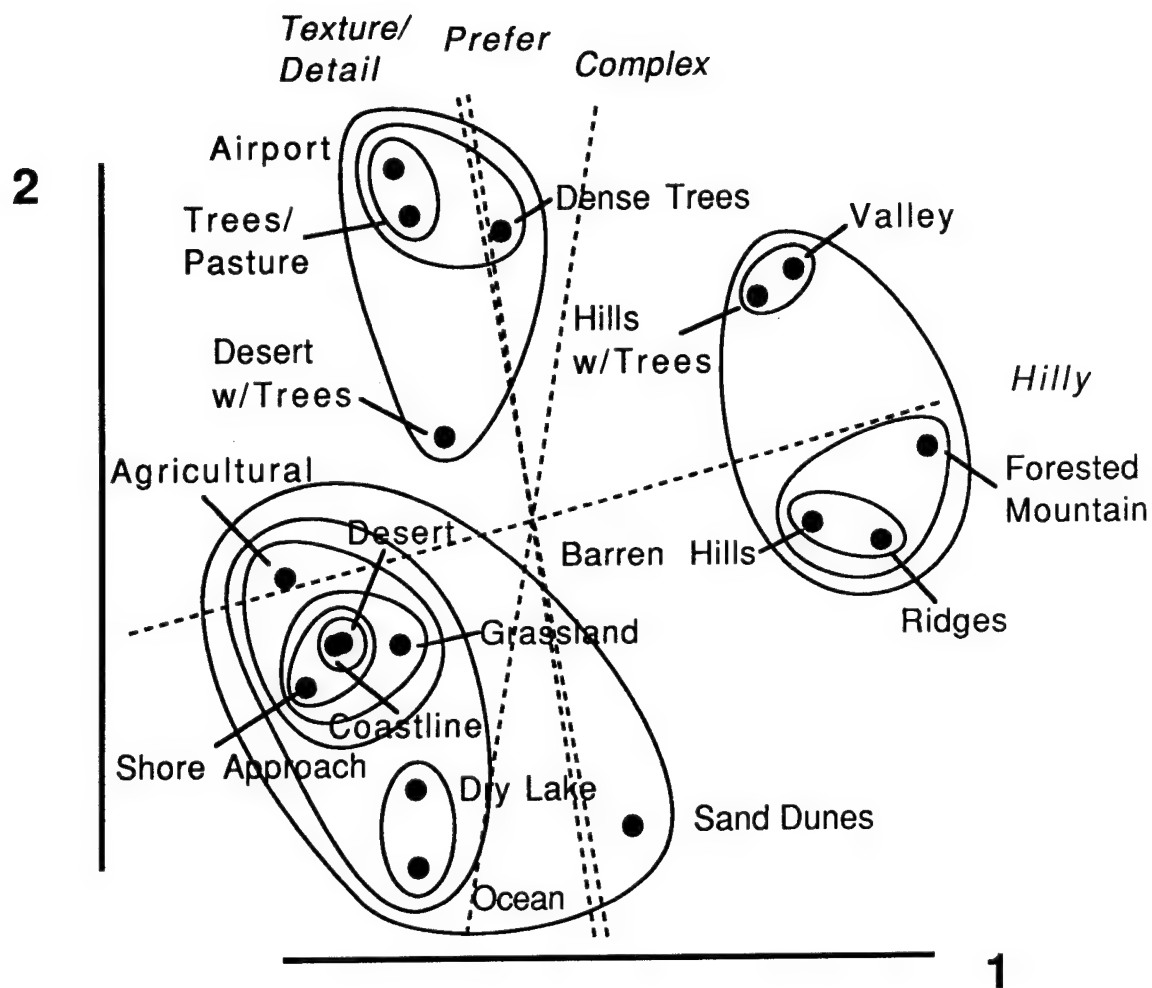


Figure 3
Two-Dimensional Spatial Configuration for A-10 Pilots

F-111

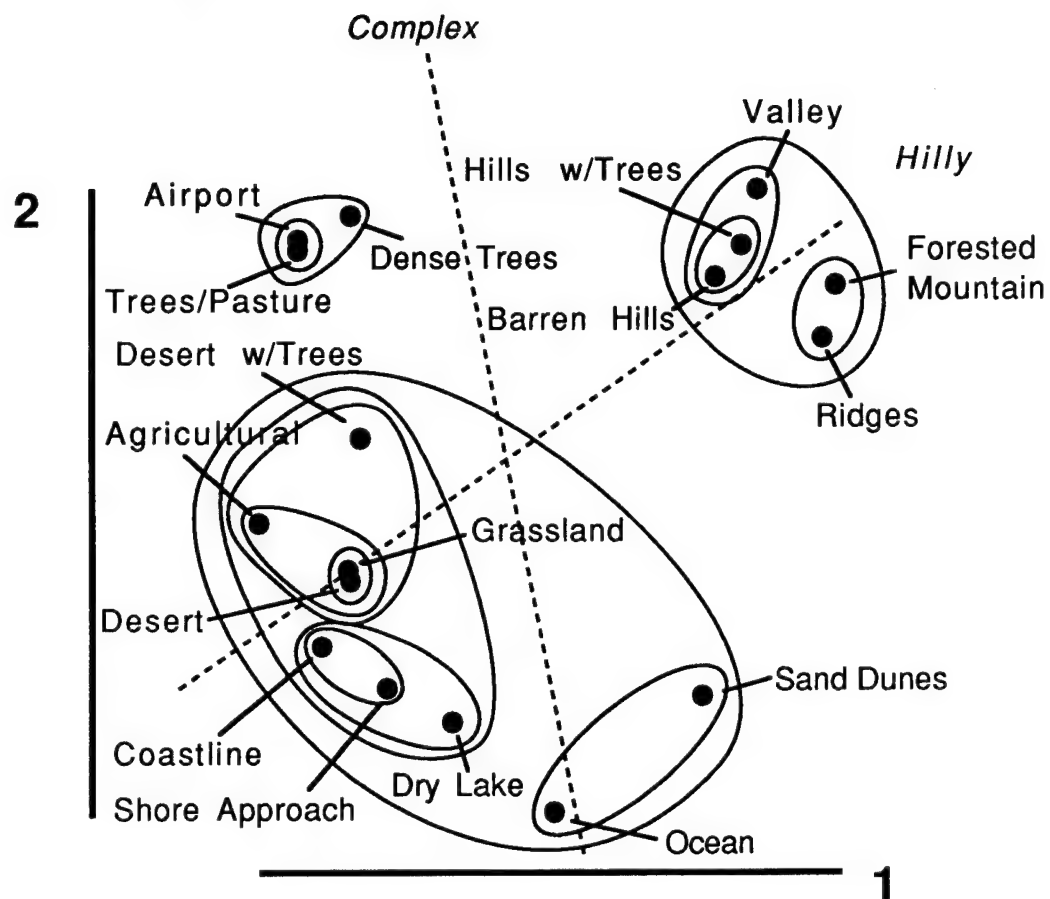


Figure 4
Two-Dimensional Spatial Configuration for F-111 Pilots

Inexperienced Pilots

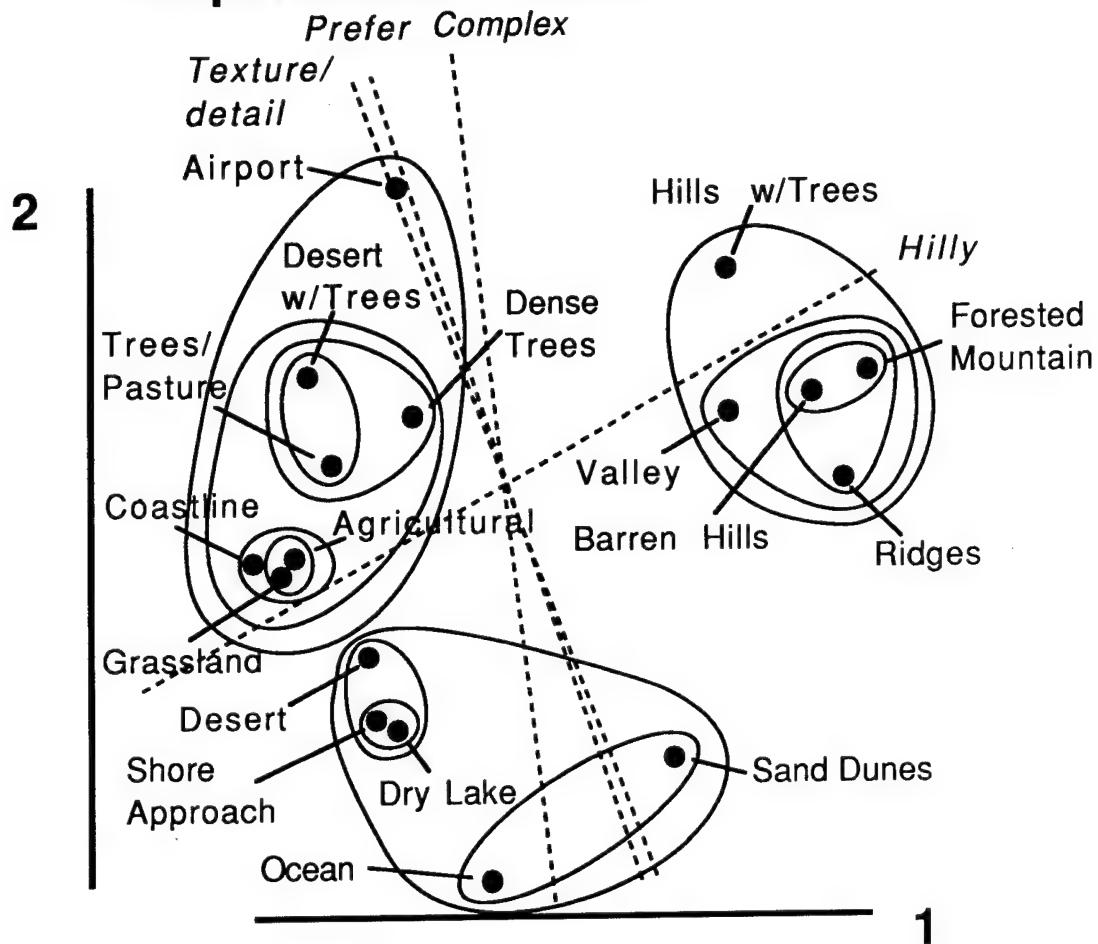


Figure 5
Two-Dimensional Spatial Configuration for Novice Pilots

Nonpilots

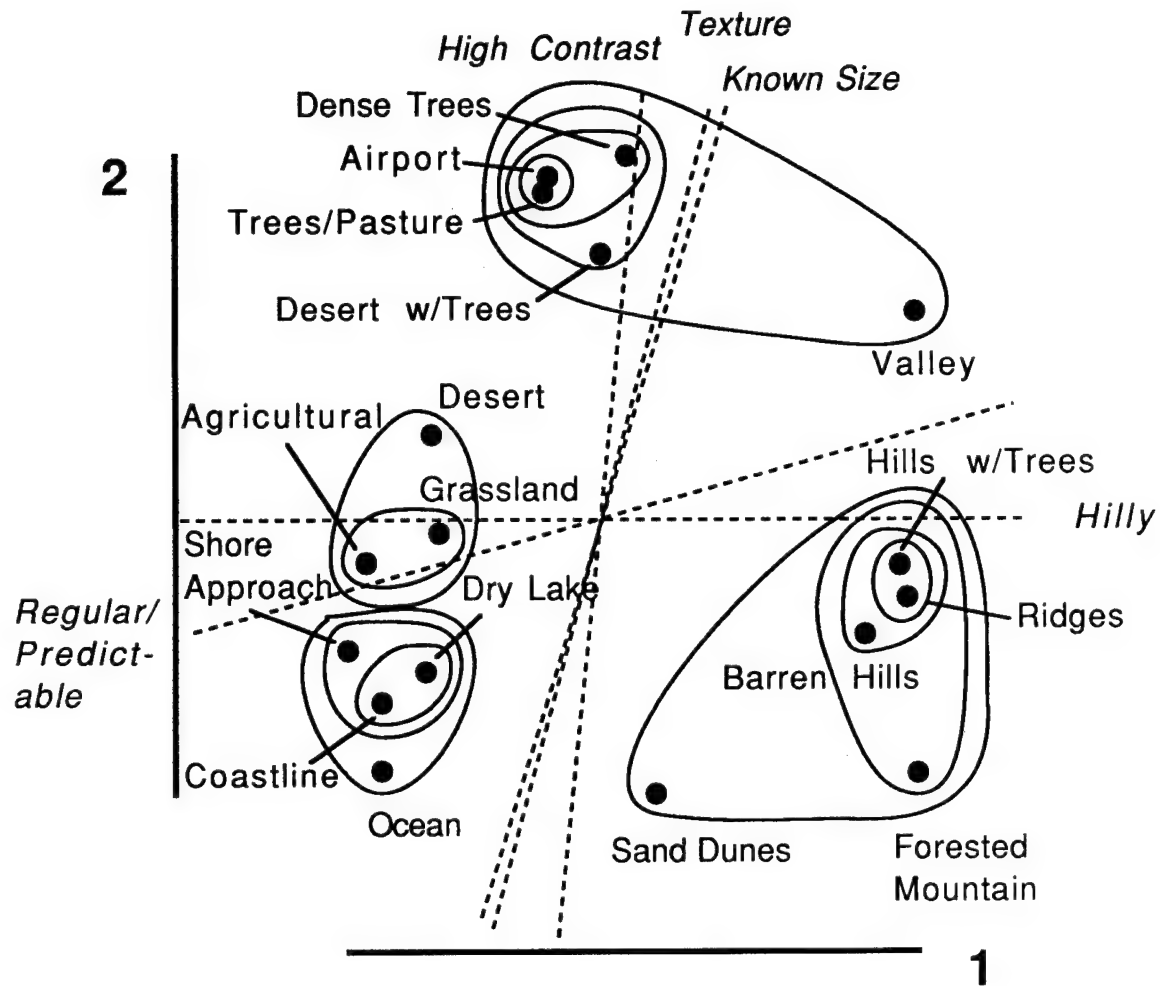


Figure 6
Two-Dimensional Spatial Configuration for Nonpilots

Composition of clusters for F-111 pilots (Fig. 4) is similar to that for A-10 pilots. However, the spatial configuration appears rotated in the counterclockwise direction. Because spatial configurations using the individual differences approach are fixed in relation to dimensional axes (Kruskal & Wish, 1986), this difference may be taken to indicate a real, albeit subtle, difference in scene properties important to F-111 pilots. Scenes containing hills and ridges are clustered in the upper-right corner of the spatial configuration at the positive ends of both dimensions. Hence, these scenes exhibit two independent properties captured by each dimension. Scenes containing large objects are positioned in the upper-left corner of the spatial configuration. These scenes are dissimilar to hilly scenes with regard to the property captured by Dimension 1, but similar to hilly scenes with regard to the property captured by Dimension 2.

Most scenes positioned at the negative end of Dimension 1 contain objects and vegetation whereas the dry lake and ocean scenes (among the flattest) are positioned near the middle of the dimension. This suggests that Dimension 1 does not capture the shape of the terrain by itself, but a property related to the gradient of texture size/density or the optical flow field. Note, also, that the hilly/mountainous property vector is not closely aligned with the Dimension 1 axis. Objects and vegetation resting upon flat surfaces provide a texture gradient and optical flow field that is continuous in depth whereas hilly scenes are discontinuous due to separation in depth of foreground and background surfaces. Depth discontinuities are also evident at the boundaries of large objects, a property to which other subjects are somewhat sensitive as evidenced by the positioning of these scenes nearer the middle of Dimension 1 axis in Figures 2, 3 and 6. However, the considerable horizontal extent of large objects appears to outweigh this fact for F-111 pilots.

Scenes containing large objects are similar to scenes containing hills and ridges with regard to the property captured by Dimension 2. The property common to all these scenes is the presence of large contours. Contours may be distinguished from objects captured by Dimension 2 for F-16 pilots, A-10 pilots and nonpilots in that contours do not necessarily bound a distinct entity in scenes set apart from the background by means of color or luminance contrast. Contours add an element of complexity to scenes and are the more important scene property (Table 7).

The spatial configuration for inexperienced pilots (Fig. 5) is most different from that for F-16 pilots. Positioning of scenes relative to the Dimension 1 axis is consistent with an interpretation along the lines of continuous versus discontinuous gradients similar to that for F-111 pilots. With regard to Dimension 2, scenes containing groups of large trees are positioned nearer flat scenes with small, dense vegetation such that a single large cluster is formed. The ordering of scenes along the Dimension 2 axis is consistent with presence or absence of contours similar to F-111 pilots. However, linear contours defining man-made structures in the airport scene appear to be particularly important. Alignment of the complexity property vector with the Dimension 2 axis indicates that contours contribute to the perceived complexity of scenes. Alignment of the texture/detail property vector with this dimension indicates that small-scale details on surfaces are also important.

DISCUSSION AND CONCLUSIONS

Results for F-16 pilots (Fig. 2) replicate previous results (Kleiss, 1990, 1992) and provide further evidence for the generality of this dimensional structure. The largest presentation format used in previous experiments was a 19-inch video monitor. To equal the present image size, a viewing distance of 18 inches (less with smaller monitors) would have been required in those experiments, a distance precluded by the physical layout of squadron briefing rooms in which data were collected. The larger image size could conceivably have stimulated peripheral vision to a greater extent than in previous experiments. Increasing image size is functionally equivalent to

reducing viewing distance and this manipulation has been shown to mediate changes in the perceived spatial layout of images as well (Cutting, 1988). In particular, image space compresses in depth as one moves closer to an image. The consistency realized across experiments with different viewing conditions indicates that the MDS methodology is robust to variation in these factors, at least within this range.

Lintern (1985) emphasized the role of perceptual differentiation, that is, discrimination of relevant from irrelevant visual information, in the acquisition and transfer of perceptual motor skill. Taking nonpilot results (Fig. 6) as a baseline, similarity to F-16 results (Fig. 2) suggests that skill for these pilots does not involve a process of attunement to scene properties that are unique to low-altitude flight. There is some evidence that an undifferentiated distribution of vegetation on flat terrain is more important to F-16 pilots suggesting increased sensitivity to this property of scenes. Even though this is not the prototypical property captured by Dimension 2, there may nonetheless be some training benefit to using scenes that exhibit this property.

Global similarity between nonpilots and F-16 pilots should not be taken to imply equivalence between groups. Present methodology is insensitive to differences in perceptual efficiency and there is ample evidence from experiments using performance-based measures that pilots are superior to nonpilots in this regard. For instance, pilots are more accurate at estimating altitude both in simulator scenes (Rinalducci, Patterson & DeMaio, 1984) and in real-world scenes (Rinalducci, Patterson, Forren, & Andes, 1985). They are also quicker and more accurate than nonpilots to detect changes in altitude in flight simulators (Kleiss & Hubbard, 1991). A further possibility is that pilots learn idiosyncratic cues unique to environments in which they routinely fly. The novel scenes used in the present experiment would not capture such learning. Indeed, the effectiveness of idiosyncratic cues may be a fruitful topic for future research.

Results for A-10 pilots replicate the finding of Kleiss (1990) that undulations in the terrain surface (Dimension 1) are less important than properties of objects (Dimension 2) to these pilots. Present results, however, do not simply imply a shift in the relative importance of dimensions, but imply a shift in emphasis on a different property of scenes captured by Dimension 2, that is, discrete objects. Using nonpilot results as a baseline, skill acquisition for A-10 pilots may be characterized as a reduction in the relative importance of undulations in the terrain surface accompanied by an increase in the importance of discrete objects.

Results for F-111 pilots also imply a reduction in the relative importance of undulations in the terrain surface (Dimension 1). Hills and ridges are nonetheless important as their contours are captured by Dimension 2. Undulations may be distinguished from contours in that undulations arise when multiple hills or ridges are separated in depth. A contour is present even with a single hill and this implies that an important factor in visual scenes is the density or spacing of hills and ridges.

Results for inexperienced pilots also imply a reduction in the relative importance of undulations in the terrain surface and an increase in the importance of contours, particularly linear contours defining large buildings. This is consistent with the high number of hours spent by this group flying in the near vicinity of air bases with large buildings and hangars. The apparent influence of this factor suggests that this group does not provide a valid basis for comparing general piloting abilities without formal low-altitude experience. However, similarity of nonpilot results to F-16 results suggests that piloting ability is not an important factor affecting the relative importance of scene properties.

Present results provide evidence that operational factors can affect the importance of various scene properties in the context of visual low-altitude flight. Since prototypical exemplars

of dimensions are similar across all groups, these differences may be of little practical importance so long as flight simulator visual scenes are rich in properties captured by each dimension. However, CIG processing limitations may force reduction in scene content. Indeed, Warren and Riccio (1985) provide evidence of increases in training effectiveness by systematically reducing scene content. Present results provide guidance as to the important dimensions along which scene content may be varied.

It would be useful to derive a general principle to predict differences among groups with regard to the relative importance of scene properties. Results similar to those for F-16 pilots have been obtained across several experiments using pilots of a variety of aircraft types (Kleiss, 1990, 1992). Similarity of nonpilot results argues that this pattern is general in nature and that discrepancies are atypical. Results similar to those for F-16 pilots, therefore, probably apply in most situations. It is tempting to attribute the difference for A-10 pilots to the relatively slower speed at which the aircraft flies. However, because the speed depicted in video segments was the same across groups, speed by itself is not the critical factor. Slower speed and missions that entail multiple attacks in a more or less limited geographic region could motivate visual strategies that emphasize discrete objects on the terrain surface rather than undulations in the terrain. However, missions for the F-111 are more similar to the F-16 so these factors alone do not provide a general basis for discriminating among groups. Limitations in out-of-the-cockpit visibility for the F-111 could conceivably force attention to different regions of the optical flow field than pilots with unrestricted visibility. A possible common factor is, therefore, the visual behavior of pilots. The possibility that differences in the visual behavior pilots interact with scene content has implications both for the design of simulator visual scenes and the use of simulators to teach low-altitude flight skills.

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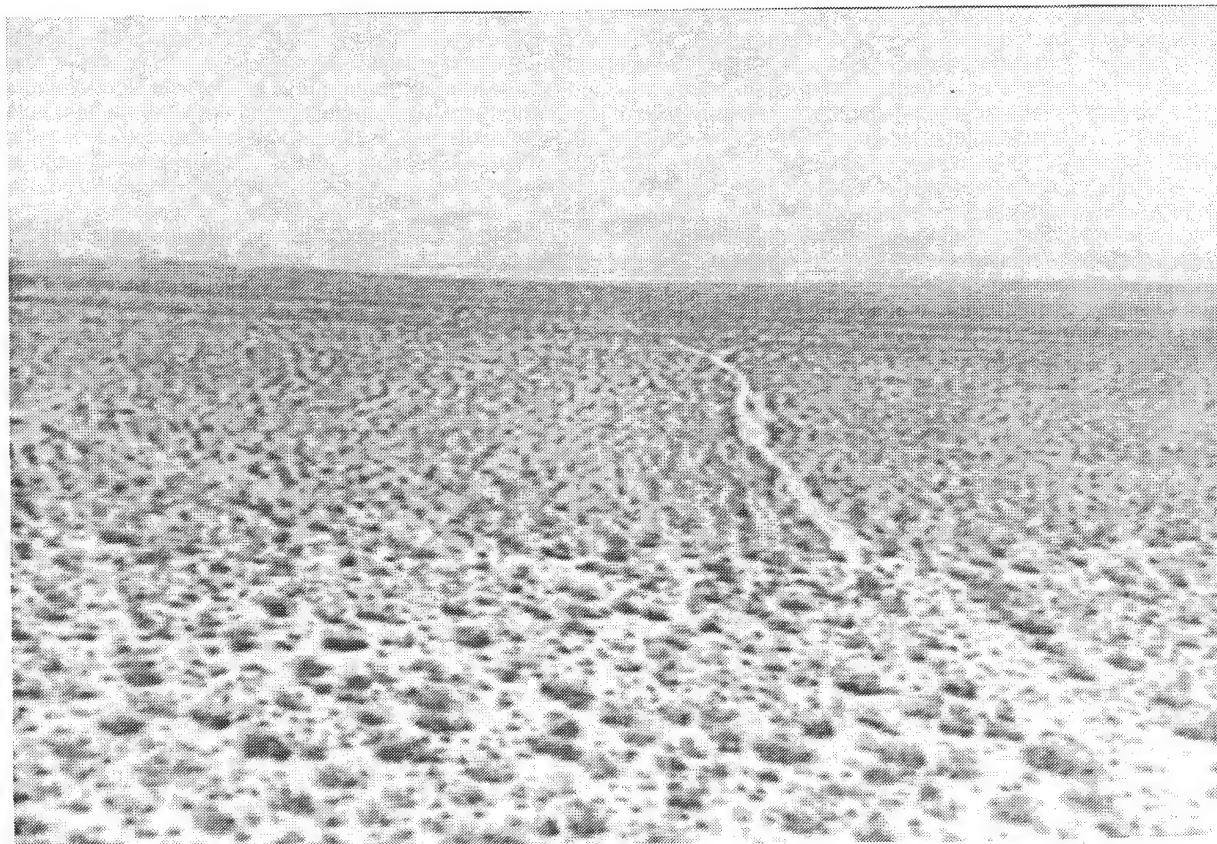
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APPENDIX A

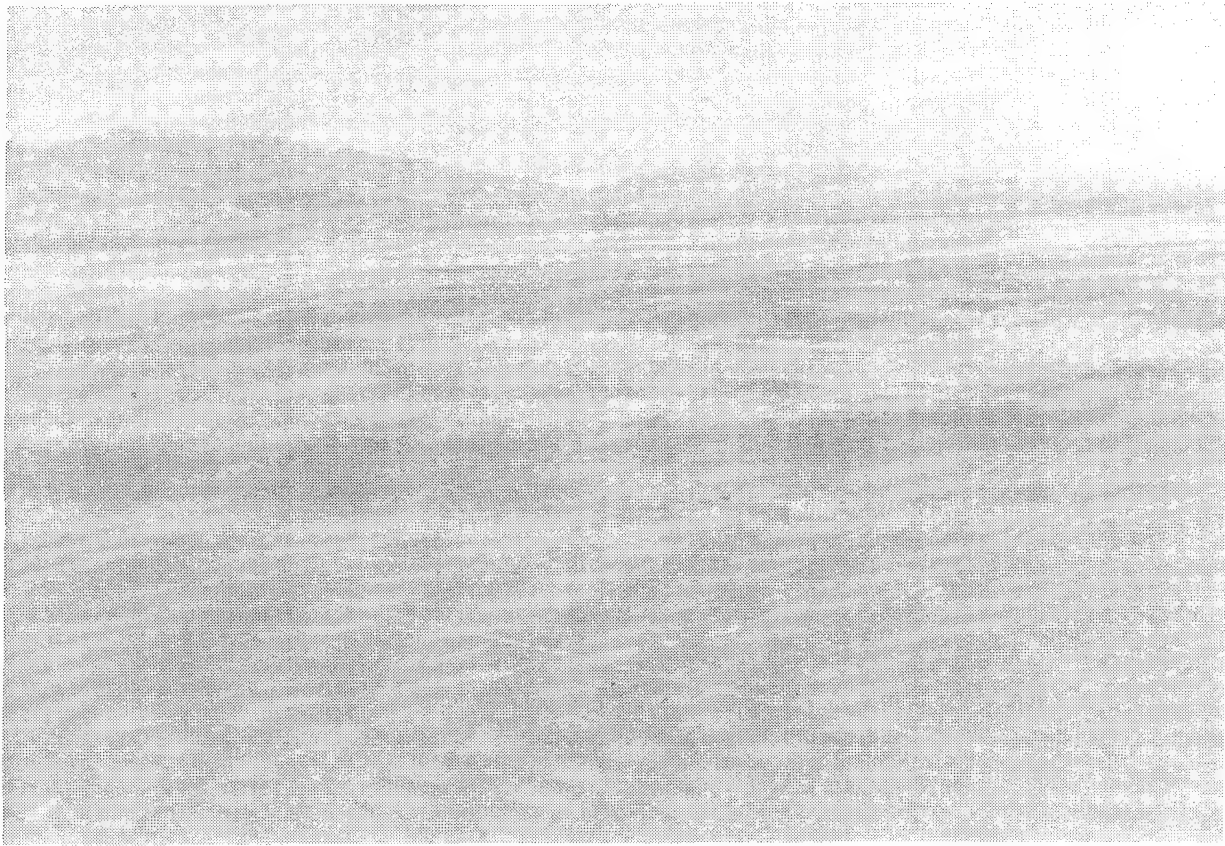
REPRESENTATIVE FRAMES FROM THE SEVENTEEN VIDEO SEGMENTS



Airport



Desert



Dry Lake



Ridges



Trees/Pasture



Dense Trees



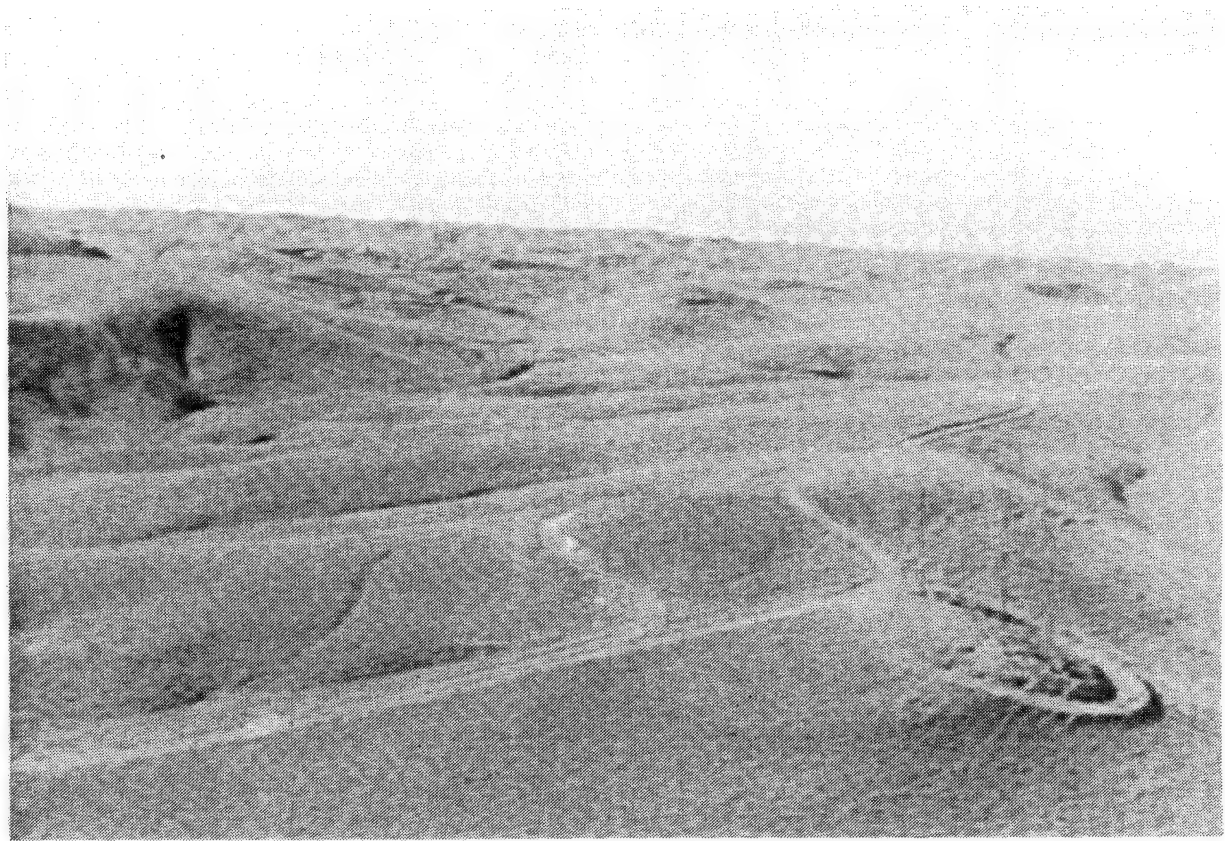
Valley



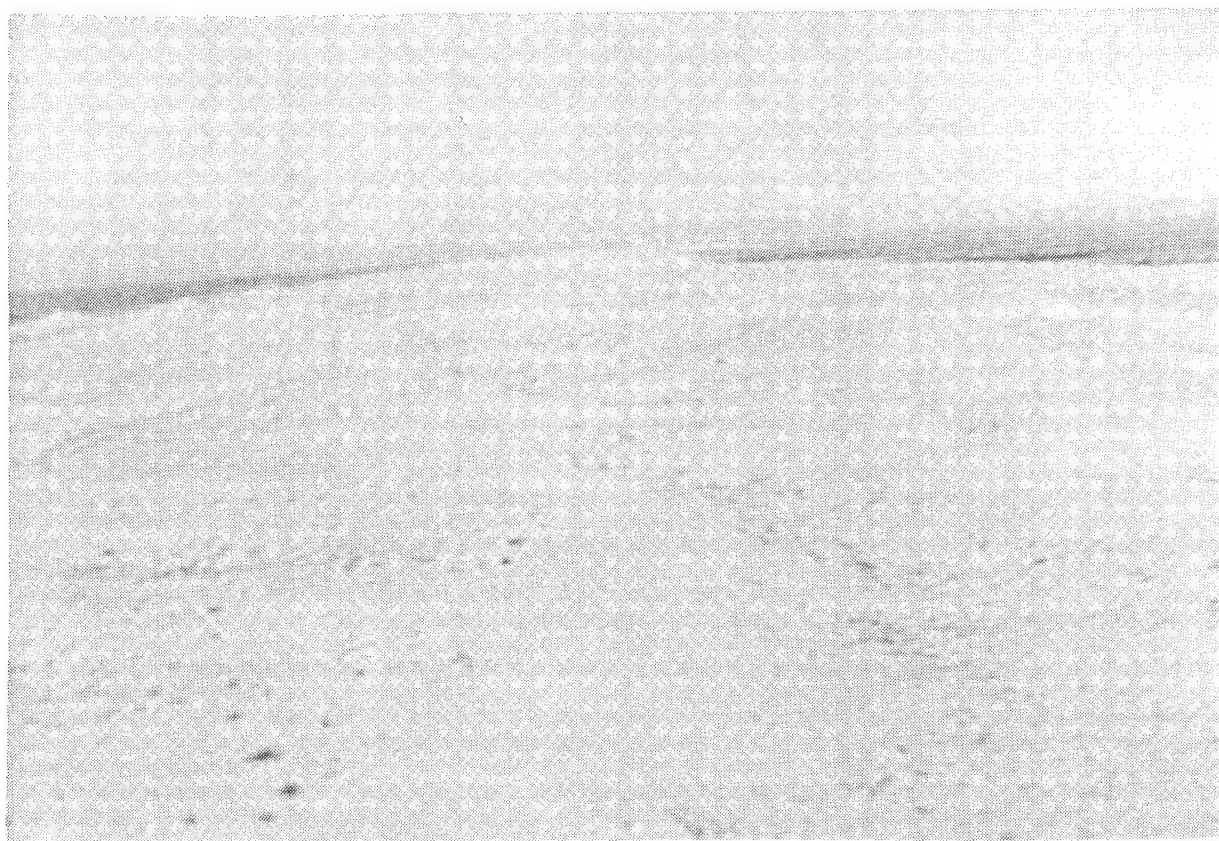
Forested Mountain



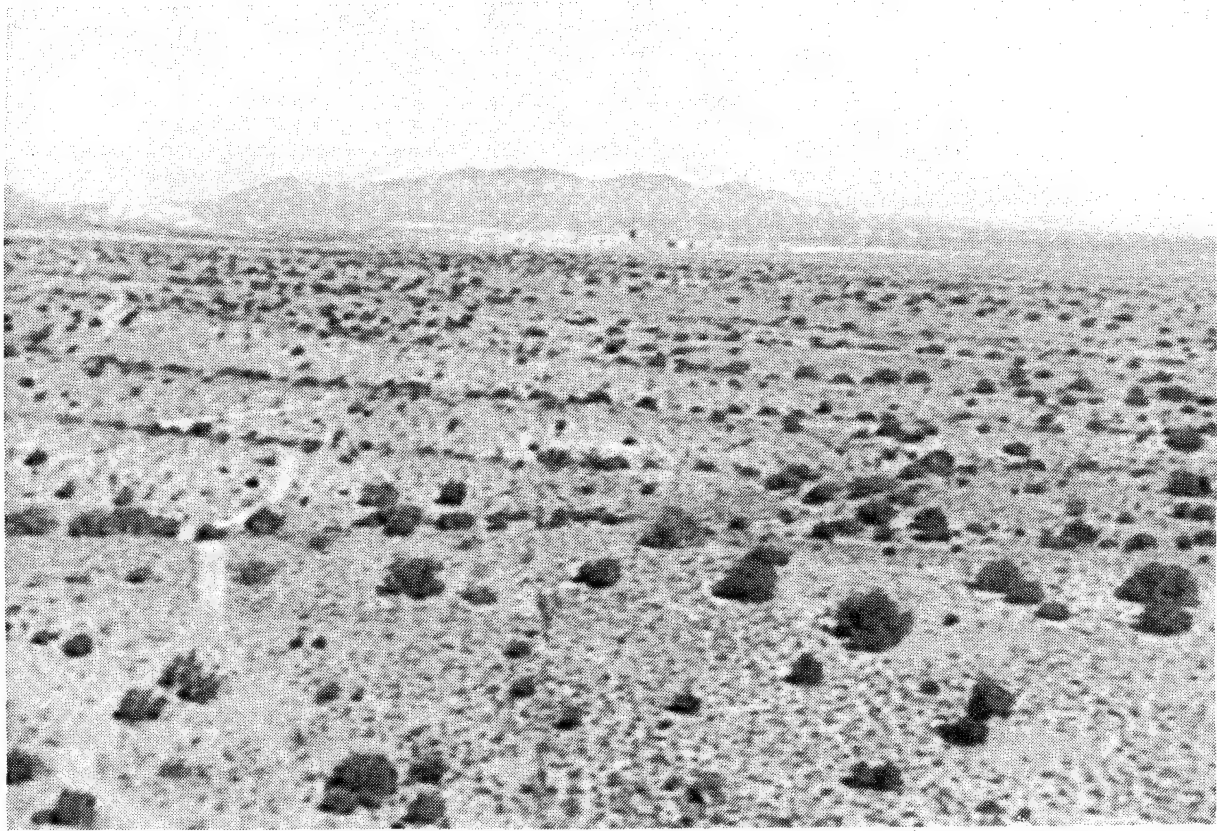
Hills w/Trees



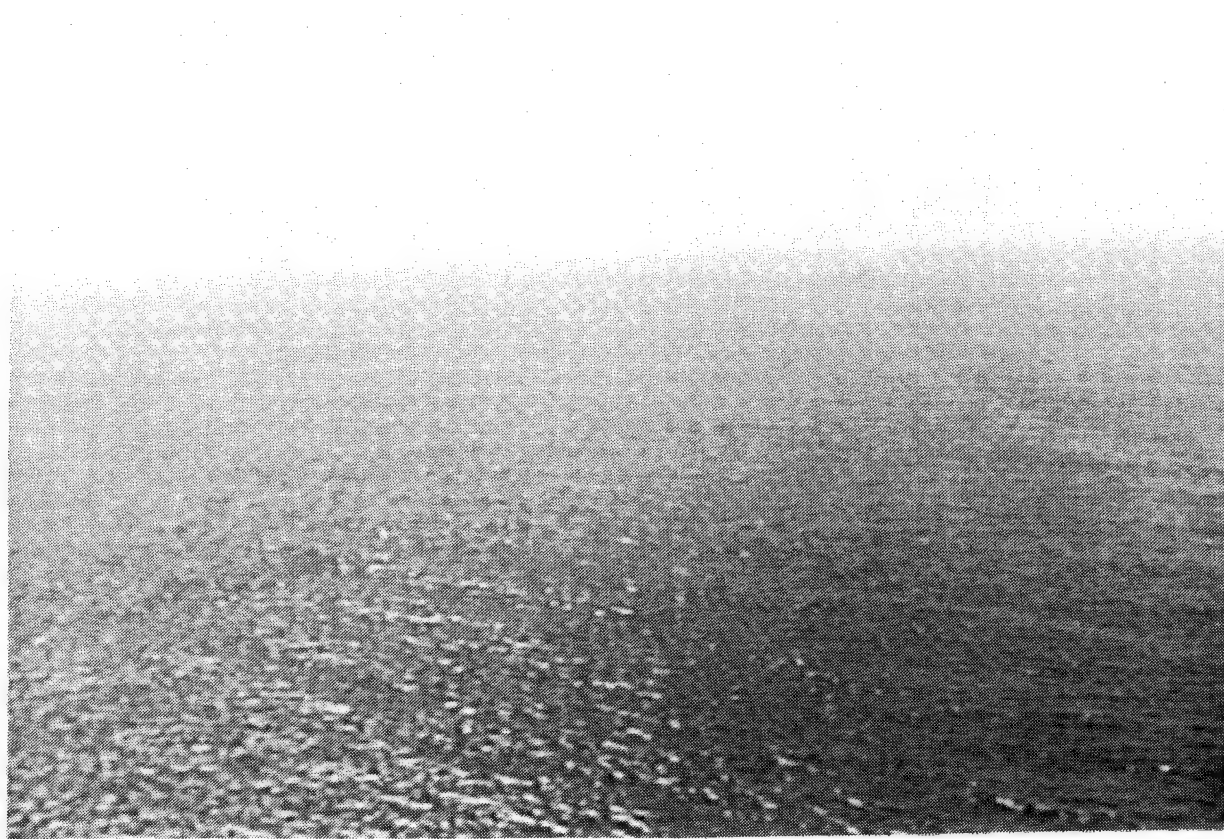
Barren Hills



Sand Dunes



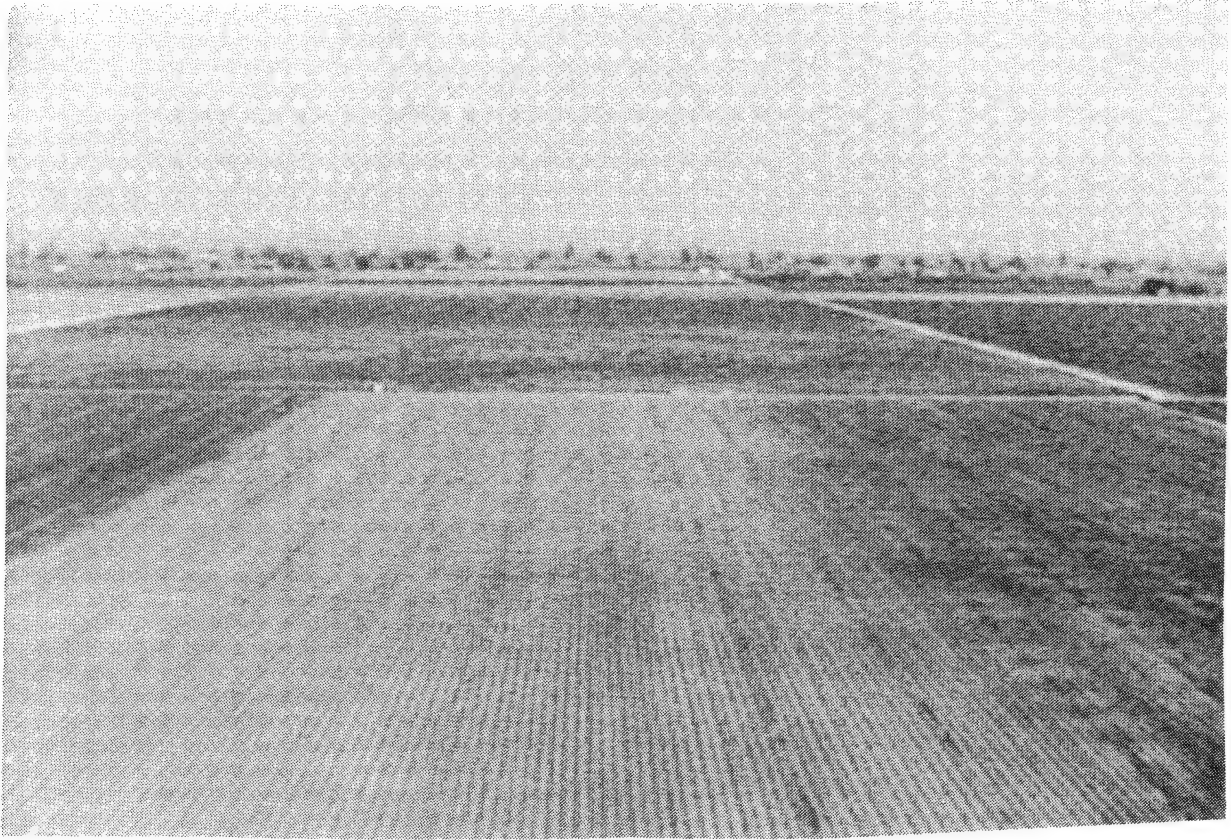
Desert w/Trees



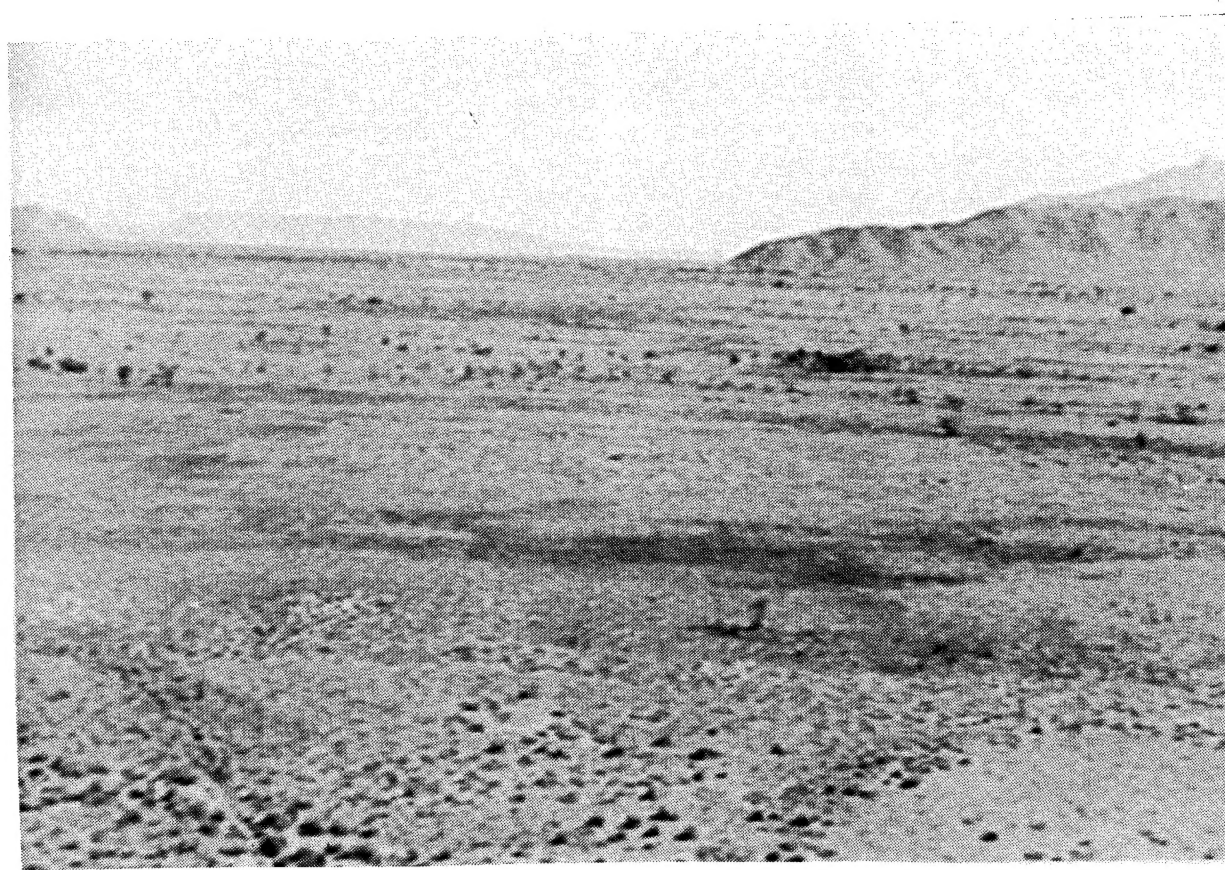
Ocean



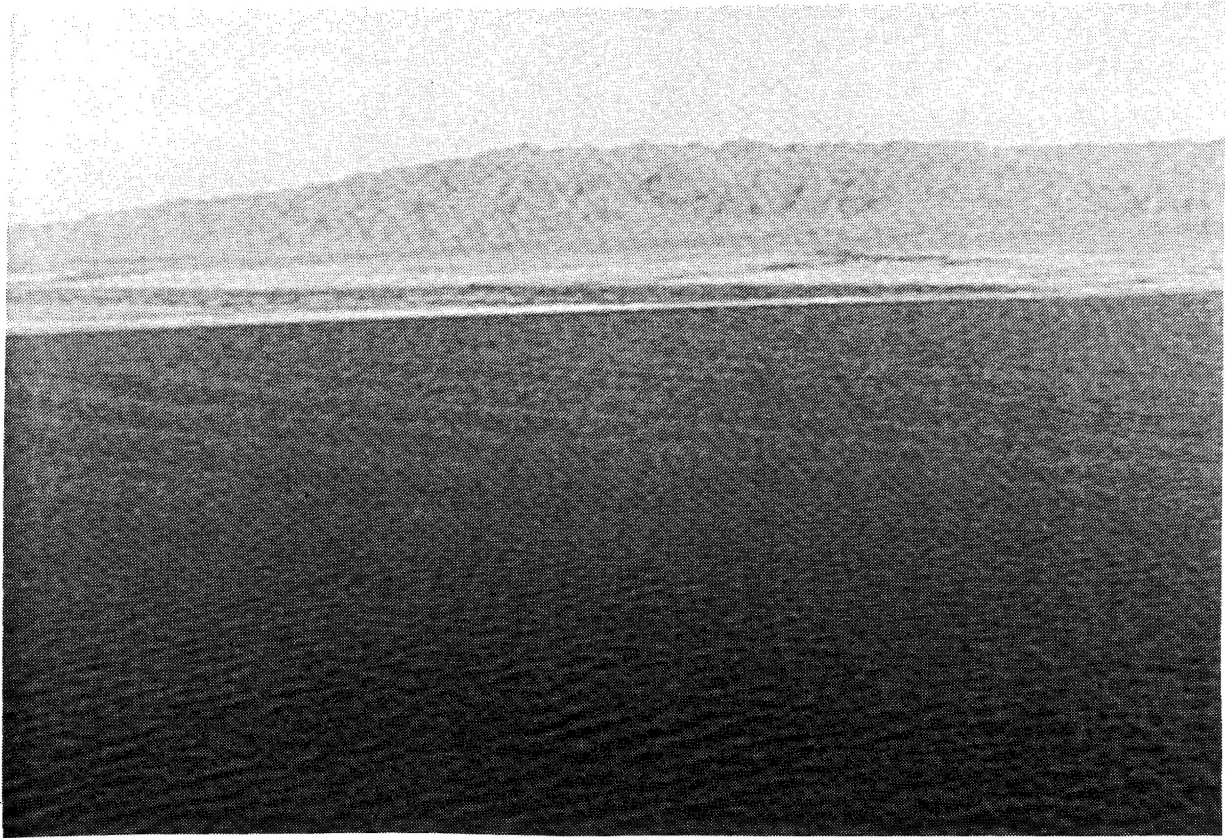
Coastline



Agricultural



Grassland



Shore Approach

APPENDIX B
INSTRUCTION PAGE

During this investigation you will be judging how similar or different a number of terrains are in terms of *visual cues for visual low-level flight*. The terrains are represented in photographs that were each shot at approximately 125 feet AGL. Imagine how the terrains would appear to you if you were flying over them at the depicted altitude. You will be comparing the terrains two at a time. For each pair of terrains a line will be provided upon which to place a mark. Below is an example:

Exact same _____ Completely different

If the two terrains appear identical, then place a mark at the end of the line by *Exact same*. If you find that there is a difference, place a mark somewhere along the line showing how much difference. *Completely different* is in the context of this particular group of terrains, so try to use the entire range that is available on the lines. It is not necessary to scrutinize the terrains or attempt to identify specific terrain characteristics that affect your judgments; a general impression of similarity is fine. In order to get an idea of how much difference there is in this group of terrains, you will be allowed to view the individual photographs before beginning.

One thing to remember is that different people judge things in different ways. Therefore there are no right or wrong answers. Two terrains may appear very similar to one person and quite different to another. Both results are important. However, please confine your judgments to terrain characteristics or visual cues that are relevant for *controlling altitude in visual low-level flight*. We are not interested in navigational features, for example, or esthetics.